Infrared for Checkout

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FOREWORD

This report was prepared by the Checkout and Launch Control Section, Support Techniques Branch, Flight Accessories Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, under Project No. 8119, "Support Equipment Techniques," and Task No. 811925, "Data Sensing for Checkout," with Ruth A. Herman as Principal Investigator. All experimentation was conducted by the Principal Investigator at the in-house laboratory facilities of the Checkout and Launch Control Section.

ABSTRACT

This report demonstrates the validity of the use of a novel method of obtaining check-out data for energized electronic circuits by an infrared technique. This technique is of special interest because it does not require power from the circuit under test, and yet it provides direct fault isolation.

Included in the report are an investigation and verification of circuit and component infrared characteristics, a brief survey of infrared detectors, a consideration of related processing techniques that are required for data analysis, and a consideration of potential applications of the technique.

This technical documentary report has been reviewed and is approved.

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INTRODUCTION

This report presents the findings of an investigation on the feasibility of infrared techniques for the checkout of energized electronic circuits. This work has included an investigation and verification of circuit and component characteristics, a brief survey of infrared detectors, a consideration of the related processing techniques that are required for data analysis, and a consideration of potential applications of the technique. The Aeronautical Systems Division (ASD) of the Air Force Systems Command is a pioneer in this field.

The theory behind the proposed technique is as follows: All objects having temperatures above absolute zero emit electromagnetic radiation, most of which is in the infrared region of 0.75 to 100 microns. The amount of infrared emitted by a body is directly proportional to the fourth power of the absolute temperature of the object, as shown by Stefan's Law, $F(T) = \epsilon\sigma T^4$, where $F(T)$ is the total power per unit area, ϵ is average emissivity, σ is Stefan's constant, and T is absolute temperature (ref 1). Because its power is dissipated as heat, an energized resistive circuit is a distinct source of thermal infrared radiation. Many of the components in an energized resistive circuit are characterized by individual normal operating temperatures, and this should theoretically result in infrared patterns that characterize the circuit as a whole. Changes in the component temperatures and overall infrared patterns should, theoretically, indicate changes in the operating conditions of the components and circuitry. If it were feasible to detect these infrared changes and relate them to the circuitry, a new method of fault isolation and failure prediction could follow. This technique would be of special interest since it would not require direct electrical connections that draw power from the circuit under test; yet it would provide direct fault isolation. This report demonstrates the validity of this theory as experimentally verified at ASD, and it identifies problems involved in utilizing the infrared technique.

COMPONENT ANALYSIS

Thermal Infrared Sources

The following components are among the potential thermal infrared sources in an energized electronic circuit: resistors, vacuum tubes, transitors, transformers, batteries, and lamps. These are resistive circuit elements. Capacitors, under certain conditions, will also display infrared changes. These components alone comprise the majority of all circuit elements. The experimentation to date has been almost entirely limited to an investigation of the infrared radiation emitted by resistors under various operating conditions. A brief look was also given to the other potential radiation sources. The experimental observations of these components as related to infrared are as follows:

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Resistor

In a circuit resistance the flow of current causes heating and a power loss equal to I^2R. To determine a close approximation for translating power loss into temperature for a resistor, power was applied in steps to a ½-watt 51-kilohm resistor. The temperature rise of the resistor was noted and plotted.

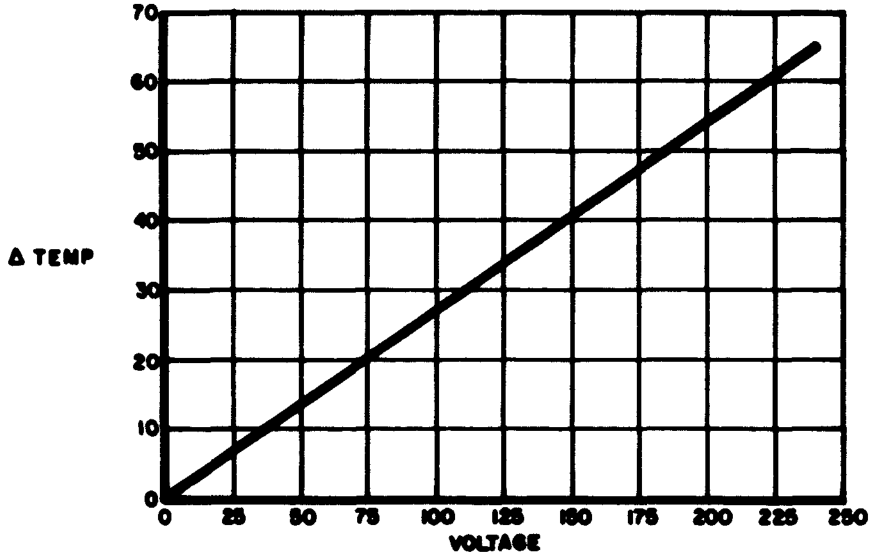

Figure 1. Plot of Temperature in °C Versus Voltage for a 1/2-Watt Resistor

The temperature increase was approximately 0.27°C per volt up to 226 volts. This rate was valid for ambient temperatures in the range of 25 ± 5°C. In reality, resistors increase resistance with increased voltage and temperature, so that the power across the 51-kil-ohm nominal resistor is less than 1 watt at 226 volts. However, in this report, the nominal value of the resistors will be used for all calculations together with the rate of 61°C per watt for consistency. The operating temperature can then be stated as $T_o = 61P + T_A$ where T_o is operating temperature in degrees centigrade, P is power in watts with the nominal resistor value, and T_A is ambient temperature within the range of 25 ± 5°C. In other words, at an ambient temperature of 28.3°C, the operating temperature of this resistor was 89.3°C at 1 watt nominal. No measurements were made above 1 watt as the resistor had started to smoke at that point. With the total power less than 1 watt and with each ⅛-watt power increase to the resistor, approximately 10 seconds were required for its temperature to begin to rise, and approximately 2 to 3 minutes for the temperature to stabilize, thus following an "S" curve plot.

Inasmuch as ambient temperatures are normally fluctuating temperatures, and these fluctuations are directly reflected in the operating temperature as shown by the equation $T_o = 61P + T_A$, the important factor is the difference between the component's temperature and the ambient temperature, rather than the component's operating temperature itself. In other words, for realistic comparative purposes, the ambient temperature must be measured and subtracted from the component's operating temperature. This tends to compensate for component operating temperature variations that occur due to ambient temperature variations. Furthermore, changes in room temperature are likely to be greater than changes in component differential temperatures caused by component faults. Fluctuations in component temperatures could be mistaken for circuit degradation without some sort of compensation. The equation for translating power in watts into the differential temperature in degrees centigrade, at an ambient temperature of 25 ± 5°C can be stated as approximately $T_e = 61P$.

Vacuum Tube

The primary infrared source in a vacuum tube is the filament. For the purpose of this study a 6SL7 tube was observed. With 6.3 volts applied to the filaments, and with a normal load applied to the grids and plates, the temperature of the glass enclosure at the filament was 52°C at an ambient temperature of 25°C. The operating temperature varied with the ambient temperature.

Transistor

In any circuit the junction temperature (T_j) is determined by the total power dissipation in the transistor (P), the ambient temperature (T_A), and the thermal resistance (K): Then $T_j = T_A + KP$. P is dependent upon T_A since an increase in ambient temperature causes a shift in the quiescent operating point which in turn causes an increase in the power dissipation. An example of the thermal resistance of a transistor is 250°C per watt for the 2N241A.

Transformer

The amount of power that a transformer can handle as indicated by its power rating is determined by its own losses because these heat the wire and core. There is a limit to the temperature rise that can be tolerated in any specific transformer. Monitoring this temperature can determine malfunctions in the transformer and in the transformer circuit.

Battery

Batteries generate heat depending on power drain. Again, monitoring this temperature would determine its operating level.

Capacitor

In an AC circuit the power in a reactance is equal to I^2X, but it is not a "loss." It is simply power that is transferred back and forth between the field and the circuit. This power is not used up in heat. A capacitor will get hot, however, when it experiences a voltage breakdown.

It was stated in the foregoing paragraphs that the operating temperatures varied with the ambient temperatures. It is also true that fans, drafts, air currents, etc., change the thermal patterns. To further establish the manner in which the component temperatures varied with ambient, an electronic circuit was placed in a temperature-controlled chamber. The circuit was energized and allowed to stabilize for one hour after which the operating temperatures of the components were measured. This procedure was followed at six ambient temperatures between 10° and 40°C. For components operating 5°C above an ambient temperature of 10°C, these components operated 2.5°C above an ambient of 40°C, and the decrease in temperature difference was essentially linear between the 10° and 40°C extremes. It, therefore, is not enough to know the temperature of a component under normal operating conditions, but it is also necessary to know the ambient temperature at that time.

CIRCUIT ANALYSIS

Component Circuit Changes

The next step toward the determination of the feasibility of using the infrared characteristics of components for checkout is to study the component changes in a circuit with respect to its faults. A vacuum-tube amplifier circuit and a transistor oscillator circuit were selected as typical for analysis. The amount of infrared to be detected was predicted, then compared with actual infrared measurements.

Vacuum-Tube Amplifier Circuit

As previously stated, in any energized resistive circuit element the amount of infrared emitted is directly proportional to the fourth power of the absolute temperature of the object. In turn, the absolute temperature of the object is a function of the ambient temperature and a function of the power losses of the object. Let us consider, first, the power losses in a vacuum-tube amplifier circuit both under normal operating conditions and with various faults applied. The circuit is shown in figure 2. This circuit was designed with the use of standard design techniques, i.e., no component values were degraded during designing.

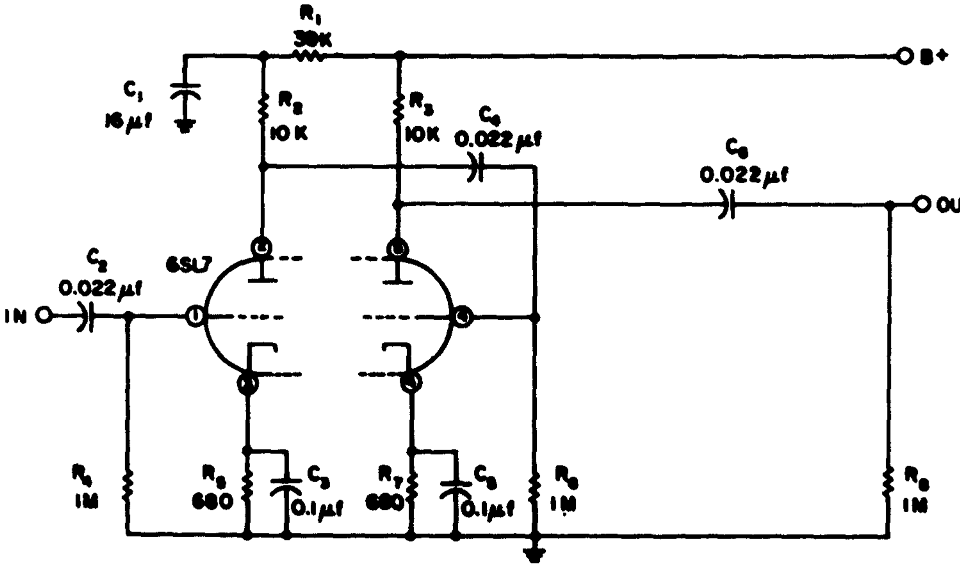

Figure 2. Vacuum-Tube Amplifier Circuit

Two methods could have been used to determine the power losses, one by actual measurement, and the other, by paper computation. To expedite this preliminary investigation, actual measurements were taken.

With 230-volts DC applied to the circuit, the voltage drops were measured across each component exclusive of the tube. Then each component was short-circuited, one at a time, and voltage drops were again measured across each of the other components. The same procedure is applicable to open circuits but measurement of the short circuits was considered sufficient for illustration (table 1) of catastrophic types of failure. Unfortunately, voltage measurements of components R_8 and R_6 with various short circuits imposed are not precisely repeatable; consequently, these measurements should be accepted on a relative basis only.

The voltage readings can be translated into power, and subsequently into expected temperature. By using the equation $P = E^2/R$ for translating the voltage readings for the various resistors into power, and by substituting the result into $T_d = 61P$ to obtain the differential temperature in degrees centigrade, gave $T_d = 61E^2/R$. Based on values in table 1, the expected component differential temperatures near an ambient temperature of 25°C are as given in table 2.

The readings appearing in the table are of ambient temperatures or above. That is, with no short circuits and with an ambient temperature of 25°C, component R_9 was expected to be operating at 28.5°C. The readings are in degrees centigrade; m stands for milli or 10^{-3} degrees centigrade, and μ stands for micro or 10^{-6} degrees centigrade.

The significance of table 2 was analyzed next, and the applicability of infrared techniques to checkout was determined as a result.

From experimental observations, differential temperatures of less than 0.5°C from ambient or from normal operating temperature are insignificant. This statement is based on inherent detector noise and the fact that the temperature of a body is never constant but is always fluctuating randomly near a mean value. Under normal operating conditions only two of the components have differential temperatures of 0.5°C or greater, as shown in table 2. These are components R_1 and R_9.

Several possibilities exist for using this knowledge of "infrared" to isolate faults. Three methods, that of looking for "hot spots," of comparing exact infrared measurements with predetermined tolerance limits, and of pattern recognition, are discussed.

If a hot spot is defined as any object having a temperature over 10°C above the ambient temperature, there are then only three different hot spots possible. These do not occur under normal operating conditions but only with two of the twelve possible short circuits. The hot spots were components R_1, R_9, and R_8 with C_4 short-circuited and component R_1 with C_1 short-circuited. If maximum fault isolation was to be achieved or even approached, it was not sufficient to look for hot spots alone.

A second possibility in detecting hot spots involved monitoring the exact operating temperatures and comparing them with predetermined tolerance limits. When a reading exceeds the limit in either direction, then a fault is known to exist. In the amplifier circuit used in this investigation, there were six different components whose operating temperatures could vary more than 0.5°C with the various short circuits. These components were R_1, R_6, R_8, R_7, R_9, and possibly C_1. However, it was only necessary to measure three of these component temperatures, R_1, R_8, and R_9, as the others could not add additional significant data. If the exact temperature difference between component R_1 and ambient were known, then short circuits in R_1, R_9, C_1, and C_4 could be isolated directly, and R_8 and C_8 could be isolated to the pair. If the temperature of R_8 were known in addition to R_1, then a short circuit in R_4, R_6, or R_9 could also be isolated to this group of three, and

TABLE I

VOLTAGE MEASUREMENTS WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR VACUUM-TUBE CIRCUIT

COMPONENTS OBSERVED	NORMAL	SHORT-CIRCUITED COMPONENTS													
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	C_1	C_2	C_3	C_4	C_5	C_6
R_1	60		65	60	60	70	60	60	60	230	60	70	150	60	60
R_2	24	33		25	24	28	24	24	24	0	24	28	60	24	24
R_3	1.6	1	27		28	1.8	28	1	28	28	1.6	1.8	180	1	4.2
R_4	0	0	0	0		.5	0	0	0	.75	0	.5	6	0	0
R_5	1	1.4	1.1	1	1		1	1	1	0	1	0	02	1	1
R_6	2.8	3	0	0	0	2		3	0	0	2.3	2	19	3	3
R_7	.1	.09	1.3	1.5	1.3	.25	1.3		1.3	1.3	.07	.25	10	0	.07
R_8	0	0	0	0	0	0	0	0		0	0	0	0	0	220
C_1	160	230	150	160	160	150	160	160	160		160	150	75	160	160
C_2	0	0	0	0	0	0	0	0	0	0		0	0	0	0
C_3	1	1.4	1.1	1	1	0	1	1	1	0	1		02	1	1
C_4	140	195	150	135	140	130	140	140	140	0	140	130		140	140
C_5	.1	.09	1.3	1.5	1.3	.25	1.3	0	1.3	1.3	.07	.25	10		.07
C_6	190	190	170	190	165	190	165	190	190	170	190	190	25	190	

TABLE 2

EXPECTED DIFFERENTIAL TEMPERATURES (°C) WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR VACUUM-TUBE CIRCUIT

COMPONENTS OBSERVED	NORMAL	SHORT-CIRCUITED COMPONENTS													
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	C_1	C_2	C_3	C_4	C_5	C_6
R_1	5.6	0	6.6	5.6	5.6	7.7	5.6	5.6	5.6	83	5.6	7.7	35	5.6	5.6
R_2	3.5	6.7	0	3.8	3.5	4.8	3.5	3.5	3.5	0	3.5	4.8	22	3.5	3.5
R_3	16m	6.1m	4.5	0	4.8	20m	4.8	6.1m	4.8	4.8	16m	20m	197	6.1m	107m
R_4	0	0	0	0	0	15µ	0	0	0	34µ	0	15µ	22µ	0	0
R_5	90m	176m	109m	90m	90m	0	90m	90m	90m	0	90m	0	36µ	90m	90m
R_6	480µ	550µ	0	0	0	240µ	0	550µ	0	0	322µ	240µ	22m	550µ	550µ
R_7	895µ	720µ	152m	200m	152m	5.7m	152m	0	152m	152m	440µ	5.7m	9	0	440µ
R_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
C_1		exceeds voltage rating													

a short circuit in R_3, R_7, C_3, or C_5 could be isolated to the group of four. The temperatures of both R_1 and R_3 had to be known in this case since it is the combination of the two measurements that is unique. If the temperature of R_8 were known, then a short circuit in C_6 could be isolated. For confirmation of these statements refer to table 3 which was prepared from the complete component-temperature chart of table 2.

TABLE 3

CONDENSED COMPONENT-TEMPERATURE TABLE (°C) FOR VACUUM-TUBE CIRCUIT

COMPONENTS OBSERVED	NORMAL	SHORT-CIRCUITED COMPONENTS													
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	C_1	C_2	C_3	C_4	C_5	C_6
R_1	5.6	0	6.6	5.6	5.6	7.7	5.6	5.6	5.6	83	5.6	7.7	35	5.6	5.6
R_3	16 m			0	4.8		4.8	6.1m	4.8		16m			6.1m	
R_8															3

The principal drawback to this method was that some of the operating temperatures required to fully isolate 100 percent of the faults were in a very low range, even lower than 0.5°C which was established as the minimum significant reading, and could not be obtained reliably. Therefore, some of the faults could only be isolated to groups of 3 or 4 components rather than to the individual fault. Furthermore, it can be seen from the condensed component-voltage chart of table 4 that if voltage measurements were taken instead of temperature measurements and compared with predetermined voltage tolerance limits in the same manner, it was possible to obtain a more complete fault isolation. If the voltages across components R_1, R_7, and C_6 were known, then short circuits in all but two pairs could probably be isolated directly.

TABLE 4

CONDENSED COMPONENT-VOLTAGE TABLE FOR VACUUM-TUBE CIRCUIT

COMPONENTS OBSERVED (VOLTS)	NORMAL	SHORT-CIRCUITED COMPONENTS													
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	C_1	C_2	C_3	C_4	C_5	C_6
R_1	60	0	65	60	60	70	60	60	60	230	60	70	150	60	60
R_7	.1			1.5		.25		0	1.3		.07	.25		0	
C_6	190		170		165		165								0

The third possibility, and perhaps the most appealing method of using infrared for checkout was by pattern recognition. Instead of taking absolute temperature measurements, changes in the differential temperature status were observed. Table 5 was prepared from the complete component-temperature chart of table 2. The "X" represents the largest initial temperature increase from normal associated with a particular short. The plus sign represents small positive temperature changes and the minus sign represents negative temperature changes. Again, only differential temperature changes greater than ±0.5°C were considered.

TABLE 5

EXPECTED DIFFERENTIAL TEMPERATURE (°C) CHANGES WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR VACUUM-TUBE CIRCUIT

COMPONENTS OBSERVED	SHORT-CIRCUITED COMPONENTS													
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	C_1	C_2	C_3	C_4	C_5	C_6
R_1	-	+			×				×		×	+		
R_2	×	-			+				-		+	+		
R_3		×		×		×		×	+			×		
R_4														
R_5														
R_6														
R_7												+		
R_8														×
C_1	+													

Table 5 shows that exact temperature measurements need not be known. Instead, theoretically, faults may be predicted, and isolated if the temperature changes or trends can be noted. For example, if the temperature of components R_1, R_2, R_3, and R_7 in table 5 increased with component R_3 showing the greatest, most immediate increase, then, theoretically, a short circuit developed across component C_4. In this case six components (R_1, R_2, R_3, R_7, R_8, and possibly C_1) had to be monitored in order to identify 9 of the 12 possible faults for a maximum isolation of 75 percent. (It is significant to note that in the case of this vacuum-tube amplifier circuit, at a constant ambient temperature there was almost perfect agreement between the predicted temperature increases and the actual temperature increases observed with short circuits imposed. With this type of circuit, the infrared checkout technique is potentially beneficial.)

Transistor Oscillator Circuit

In like manner a transistor oscillator circuit was examined under normal operating conditions and also when various faults were applied. The circuit is shown in figure 3.

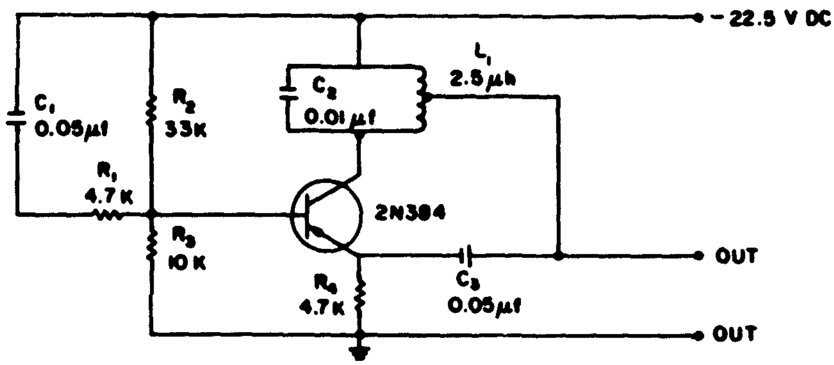

Figure 3. Transistor Oscillator Circuit

With the circuit energized, the AC and DC voltage drops were measured (table 6) as with the previous vacuum-tube circuit.

TABLE 6

VOLTAGE MEASUREMENTS WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR TRANSISTOR CIRCUIT

COMPONENTS OBSERVED (VOLTS)	NORMAL	SHORT-CIRCUITED COMPONENTS							
		R_1	R_2	R_3	R_4	C_1	C_2	C_3	L_1
R_1	.1		0	0	0	7	0	0	0
R_2	16.35	16.25		22.5	16.25	7	16.25	0	16.25
R_3	5.35	5.25	22.5		5.25	16.5	5.25	0	5.25
R_4	5.4	9.1	4.7	4.7			4.7	0	4.7
C_1	0	0	0	0	0		0	0	0
C_2	9.5	11	7.5	7.5	7.5			0	7.5
C_3	.1	.4	0	0	0	.3	0		0
L_1	9.5	11	7.5	7.5	7.5		7.5	0	

Again, using equation $T_s = 61E^{a}/R$, the voltage readings were translated into expected differential temperatures in degrees centigrade (table 7).

TABLE 7

EXPECTED DIFFERENTIAL TEMPERATURE (°C) WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR TRANSISTOR CIRCUIT

COMPONENTS OBSERVED	NORMAL	SHORT-CIRCUITED COMPONENTS							
		R_1	R_2	R_3	R_4	C_1	C_2	C_3	L_1
R_1	0	0	0	0	0	.64	0	0	0
R_2	.5	.5	0	.5	.5	.09	.5	0	.5
R_3	.17	.17	3.1	0	.17	1.7	.17	0	.17
R	.38	1.07	.29	.29	0		.29	0	.29

Next, the expected significant differential temperature changes were determined and considered. For the previous vacuum-tube circuit, 0.5°C was determined as the smallest significant differential temperature. For a transistor circuit, it was conceivable that the smallest significant differential temperature would be less than 0.5°C. However, in the absence of precise measurements, 0.5°C was still the smallest significant change observable at that time. The expected differential temperature changes equal to or greater than 0.5°C were shown in table 8.

TABLE 8

EXPECTED DIFFERENTIAL TEMPERATURE (°C) WITH RESPECT TO SHORT-CIRCUITED COMPONENTS FOR TRANSISTOR CIRCUIT

COMPONENTS OBSERVED	SHORT-CIRCUITED COMPONENTS							
	R_1	R_2	R_3	R_4	C_1	C_2	C_3	L_1
R_1					+			
R_2		-					-	
R_3		x			x			
R_4	x							

The transistor circuit (table 7) showed that the expected changes were radically smaller than those in the vacuum-tube circuit. In fact, they were so small as to appear to be normal fluctuations. Only four of the eight possible short circuits were identifiable so that there resulted a maximum isolation of only 50 percent of the short-circuited components. Because of inherent environmental changes and low voltages in this circuit under any condition of fault, infrared checkout in the case of this transistor circuit was not considered practical.

Infrared Checkout Effectiveness

For transistor circuits of higher power and for vacuum-tube circuits, an infrared checkout technique is potentially beneficial. Even if infrared is only used as a supplementary technique it can often be an effective way to obtain additional information, as shown by the vacuum-tube amplifier example. In addition to resistors there are other distinct infrared sources in energized electronic circuits that might well be monitored with significance. These include vacuum tubes, transistors, transformers, etc., as previously discussed. In view of this potential utilization of infrared for checkout, the various detectors and associated processing techniques were observed.

INFRARED DETECTORS

The two main types of infrared detectors are thermal and photoelectric. Both types work by absorbing a photon, or quantum, of radiation. However, in the thermal detector, the energy of the absorbed photon is transferred to lattice vibrations, and a local temperature rise is detected; whereas, in the photoelectric detector, the absorbed photon causes a change in the state of the electron distribution and this change is detected (ref 2).

An important difference between these two types of detectors is their response. Since energized circuits generally operate near 300°K the infrared region most important to this study lies approximately between 8 and 14 microns. The region can be determined from tables such as the one provided by General Electric Company (ref 3). Photoelectric detectors have limited, nonuniform responses in the wavelength involved; hence they must be cooled to liquid-nitrogen temperatures so as to be responsive to radiation from objects below incandescence. On the other hand, thermal detectors have a flat response over a broad band from ultraviolet through far infrared and do not require cooling (ref 4).

For convenience we considered the infrared changes in terms of temperature. However, neither the photoelectric nor the thermal detector required direct contact with the radiation source for accurate detection, and either could be located some distance away. It depends on the amount of radiation to be observed and the distance of the detector from the source whether or not an optical system may be required to collect and focus the energy onto the detector when direct contact is not made.

Photoelectric detectors that could have been used include lead selenide, and zinc or gold-doped germanium. The thermal types include the thermistor, the thermocouple, and the Golay detector.

ASSOCIATED PROCESSING TECHNIQUES

Two Additional Detector Categories

To facilitate the investigation of associated processing techniques, infrared detectors can be divided into two additional classes: (1) point detectors, and (2) area, or extended, detectors (ref 5). Point detectors have a sensitive surface that integrates all incident radiant energy into a single expression. They include radiation thermocouples, pneumatic-type detectors, and bolometer-type detectors. Area, or extended, detectors provide a picture of the radiation pattern. They include image tubes, vidicons, and evaporographs. This section will be limited to general remarks about the advantages and disadvantages of processing techniques associated with these two classes of detectors as applied to fault isolation techniques.

Point Detectors

The point detector can be used in at least three ways:

(1) In one method a probe can be placed, one at a time, on each component being monitored. A temperature differential indicator will provide readings (operating temperature minus ambient temperature) that can be compared with a standard list of readings for the particular unit under test. From changes in readings (initial, positive, and negative) the fault can theoretically be isolated. This is an entirely manual, bench-type method that bypasses all optical and cooling constraints, and that looks promising.

(2) Specially matched probes can be permanently mounted directly on all components being monitored. A sequencer can sample each probe, one at a time, continually scanning the circuit. This method is adaptable to either semiautomatic or completely automatic techniques and may be used on the bench or in flight. It also bypasses all optical and cooling constraints. This is the method that was primarily investigated by this laboratory and is discussed in detail later in the report.

(3) Point detectors can be placed in a matrix to form an area-type detector. The matrix can be located immediately above or below the components being checked. This method must be completely automatized and can be used on the bench or used in flight if the associated processing equipment can be kept light in weight. Fault isolation in this case depends on either locating hot spots or on locating thermal pattern changes. The original matrix pattern can be stored in a computer and subsequent patterns can be compared with it by means of the computer. As pointed out previously, an optical system is required if the detector is removed to a distance from the component or radiation source. Even with a matrix placed as close as 3 or 4 inches from the infrared source, it is doubtful that anything other than hot spots (temperatures 10°C or greater above ambient) could be sensed and located accurately without an optical system. The feasibility or applicability of this matrix technique would be determined by the amount of detectivity required, that is, the degree of infrared change of interest and the amount of auxiliary equipment to be employed.

Area Detectors

Area detectors are primarily pattern recognition devices. The components are scanned and an image is formed of the radiation intensity of the components. As with the matrix technique, a computer stores the original image, compares it with subsequent patterns, and prints out significant variations. With this method the components to be observed must be exposed; they cannot be hidden by other components, covers, etc. The scanner is likely to be in the form of a television camera, and its distance from the circuit would depend on the area to be scanned and the focal length of the lens. It would require considerable working space.

To recapitulate, considerations that will apply in selecting an infrared detector and processing technique are as follows:

(1) Component operating temperatures to be monitored

(2) Degree of infrared changes to be monitored

(3) Location of checkout (bench, in-flight, etc.)

(4) Component accessibility

(5) Required location of detector with respect to radiation sources

(6) Surrounding temperatures

(7) Ventilation of chassis under test

(8) Detector parameters

(9) Associated processing equipment required

POINT-DETECTOR ISOLATION TECHNIQUES

For the purpose of determining the feasibility of detecting infrared changes for fault isolation, point detectors were mounted directly on the components to be monitored. This method by-passed the optical and cooling constraints of the other methods but provided for the detection of immediate, minute, precise changes. Of the many thermal infrared point detectors on the market, the thermistor seemed most applicable to the component checkout probelm. Thermistors are thermal resistors with a high negative temperature coefficient of resistance. As the temperature increases, the resistance goes down, and as the temperature decreases, the resistance goes up. They are small and weigh but a few milligrams, so can easily be placed in cramped quarters and in direct contact with the components being monitored. The components themselves need not be exposed to view.

The required associated circuitry was also simple, lightweight, and easy to interpret. A sensitive temperature control was made by placing a thermistor in one leg of a bridge circuit, a variable resistor in another leg, and a high gain amplifier followed by a relay across the output. AC was applied to the bridge. (Such controls can operate to a precision of .0005°C (ref 6).) After thermistors, measuring approximately 2000 ohms at 25°C, were mounted directly on the components being monitored, and after warmup of the equipment under test, the resistances of the thermisotrs were balanced at ambient temperature by placing resistors in series with the thermistors. A sequencer was designed to sample each thermistor, one at a time, and feed the sample to the controller which in turn would stop the sequencer at the point when the balanced value was exceeded due to faults. With this arrangement the whole circuit was continuously scanned so that minute temperature changes could be noted easily, accurately, and rapidly. The unbalanced position could also be indicated by an out-of-tolerence light, or a computer could look for changes and print out the probe location or perhaps the name of the component that had changed and its degree of change. The vacuum-tube amplifier circuit delineated previously in this report was used for this experiment. The following results were obtained:

At a constant ambient temperature at which the thermistors were balanced there was almost perfect agreement between the predicted temperature increase and the actual temperature increases observed with short circuits imposed. The fault that did not show up was in capacitor C_1 when R_1 was short-circuited. It is believed that this would have appeared anyway after a sufficient length of time because the capacitor was only rated for 200 volts, but 230 volts was being applied. The maximum time allotted for a temperature increase was 5 minutes. As for temperature decreases associated with short circuits, they were not immediate and did not show up within a 3-to 5-minute period. With no short-circuited components and with warmups exceeding an hour, the DC power was cut and the tube began to cool immediately. After 2 minutes, component R_1 began to cool and after another 1-1/2 minutes component R_9 began to cool. After 12 minutes the AC power was cut and further cooling was then noticed, but this seemed to be due to cooling of the ambient temperature following the cooling of the tube. This confirms the information in table 2 that only components R_1 and R_9 were operating significantly above ambient.

The above arrangement was satisfactory when the ambient temperature was constant. However, under normal conditions ambient temperature changes will always exist, so approaches must be taken to compensate for them so that they can be distinguished from changes due to faults. A reference thermistor is required to vary the controller relative to the ambient temperature to compensate for these changes and so that the differential temperature may be obtained directly. An adequate reference was not available for this preliminary investigation. Also, with changes in the ambient temperature, the thermistor balance changed radically due to individual rather than matched temperature-resistance curves. Therefore, specially matched thermistors are also required.

The following will further illustrate what is meant by this requirement for specially matched thermistors. Thermistors of 2000 ohms at 25°C, with ±20 percent accuracy were used in this experiment. One thermistor was actually 2000 ohms and another was 2250 ohms at 25°C. They could be balanced at 25°C by placing a 250-ohm resistor in series with the 2000-ohm thermistor, thus balancing them at 2250 ohms. However, when the ambient temperature changes, the thermistors become unbalanced. For example, if the ambient temperature rises to 30°C, the 2250-ohm thermistor then measures 1861 ohms (2250 x 0.827), but the 2000-ohm thermistor, with series resistor, measures 1904 ohms (2000 x 0.827 + 250) thus presenting an out-of-tolerance condition. Thermistors with identical temperature-resistance curves would help eliminate this problem of unbalance.

Not only are thermistors with identical temperature-resistance curves necessary, but identical temperature-resistance curves at the individual component operating temperatures are desirable also in order to accomplish automatic fault isolation with a minimum of checkout equipment. Suppose one component (No. 1) normally operates at ambient temperature, and another (No. 2) operates at 5°C above ambient. If a 2000-ohm thermistor is mounted on component No. 1 and a 2418-ohm thermistor (2000 ÷ 0.827) is mounted on component No. 2, then under normal operating conditions, these thermistors are balanced at 2000 ohms at 25°C. They will also be balanced at all other ambient temperatures. When another matched 2000-ohm thermistor at 25°C is used to keep an indicator or controller zeroed at any ambient temperature, then the meter should indicate true deviations in component operating temperatures.

An arrangement like the one just described, where each key component is continually scanned, could probably be used for failure prediction. When a deviation greater than 0.5°C is observed, then a pattern of deviation could possibly be established that would define the fault that is occurring. In this way, even before the potential fault noticeably affects the circuit performance, it is conceivable that it can be predicted and isolated. It is planned to investigate this possibility further.

SUMMARY AND CONCLUSIONS

The experimentation as presented in this report includes an analysis of certain resistive components and circuits, and it describes the magnitude of infrared changes that can be expected under various operating conditions. This analysis established that, within limits, faults can theoretically be isolated through infrared detection and processing techniques. These limits depend on the accuracy of the detection and processing equipment.

The theoretical validation of the infrared checkout technique was followed up with laboratory studies of actual component changes. The laboratory studies confirmed the theoretical work in that the changes greater than 0.5°C that were predicted were also detected. However, there were changes of less than 0.5°C that were essential for complete fault isolation that could not be detected with the present laboratory equipment.

This report also describes various infrared detection and processing techniques that can be used. The laboratory study utilized a point detection technique. The sensors that were used were thermistors. Proper selection and matching of thermistors was found to be essential for minimizing the acquisition of erroneous data.

Results of the experimentation to date are encouraging even though there are still obstacles to overcome as described above. The validity of the infrared technique for the checkout of energized electronic circuits was proved and shown to be potentially beneficial even if only in conjunction with other checkout techniques as a means for obtaining additional checkout information. The technique is of special interest since it cannot change the characteristics of the circuit under test.

Resistors in particular were stressed in this report. Further experimentation will include (1) a more extensive study of other components as well as resistors, (2) an investigation of the applicability of infrared to failure prediction, and (3) a laboratory study of various detection and processing techniques.

Other general conclusions are summarized as follows:

a. Components with faults do change temperature.

b. Infrared patterns do characterize the operating condition of a resistive circuit.

c. Infrared patterns are observable by various sensing and processing techniques except in low power circuits.

d. Choice of sensing and processing technique depends on planned application, e.g., in-flight, bench, etc.

e. Only key components need to be monitored.

f. A search for hot spots is not alone sufficient for maximum fault isolation.

g. The temperature difference (component temperature minus ambient temperature) is the important factor.

h. Infrared pattern recognition techniques look promising for failure prediction work and as a supplement to other checkout techniques.

LIST OF REFERENCES

1. Smith, R. A., Jones, F. E., and Chasmar, R. P., The Detection and Measurement of Infrared Radiation, Oxford Press, New York, N. Y., 1958.

2. Wolfe, W. L., and Limperis, T., "Quantum Point Detectors," Space/Aeronautics, November 1961.

3. Chernoch, J. P., "Infrared Calculations Made Simple," Aviation Age, July 1957.

4. Wormser, E. M., and DeWaard, Russel, "Thermal Detectors," Space/Aeronautics, November 1961.

5. Kovit, Bernard, "New Designs, New Applications," Space/Aeronautics, November 1961.

6. Fenwal Electronics Manual No. EMC-4, Thermistor Manual, Fenwal Electronics, Incorporated, Framingham, Mass.

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt No. ASD-TDR-63-327. INFRARED FOR CHECKOUT. Final report, May 63, 17p., incl illus., tables, 6 refs.

Unclassified Report

This report demonstrates the validity of the use of a novel method of obtaining checkout data for energized electronic circuits by an infrared technique. This technique is of special interest because it does not require power from the circuit under test, and yet it provides direct fault isolation.

Included in the report are an investigation (over)

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1. Checkout Techniques
2. Data Sensing
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